AD-A123 117 DEVELOPMENT OF THE PRECISION APPROACH PATH INDICATOR LIGHT UNIT(U) ROYAL AIRCRAFT ESTABLISHMENT FARNBOROUGH (ENGLAND) A J SMITH JUL 82 RAE-TM-FS(B)-483 1/1

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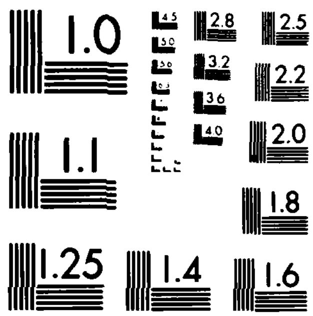

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ROYAL AIRCRAFT ESTABLISHMENT

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Technical Memorandum FS(B) 483

Received for printing 15 July 1982

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1 INTRODUCTION

The Precision Approach Path Indicator (PAPI) is a simple visual aid that has been developed to assist pilots during their approach to landing. The development of the system by the RAE was reported in Ref 1 and the operational trials and technical evaluation by ICAO were reported in Ref 2.

The PAPI system (Fig 1) uses a set of four two-colour high intensity light projectors. Each beam consists of a white upper half and red lower half. The transition from one colour to the other occurs over a very small angle. This sharp transition is an essential feature of the PAPI system and it is therefore important that all units should exhibit this characteristic. Similarly, operational considerations dictate the minimum beam-spread and intensity requirements for the light projectors. It is essential that the correct isocandela specification is adhered to in all PAPI units.

Since the PAPI light units incorporate a projector lens it is necessary to engineer the units so as to prevent the degradation of signal that can occur due to the presence of water droplets or ice particles on the surfaces of the lenses and any protecting windows.

This Memorandum reviews these various optical and engineering design parameters, and describes test procedures and engineering solutions that have been developed to ensure that they are met. This work was conducted with the active co-operation of Barrel Lighting, GEC, Research Engineers and Thorn EMI Lighting, all of whom provided light units for the test programme.

2 SHARP TRANSITION

2.1 The requirement

Experience with the PAPI system has highlighted the importance of specifying methods by which the sharp transition characteristic can be satisfactorily demonstrated and measured. Purchasing authorities must be assured that projector units have the necessary sharp transition, and installation personnel need a precise location of the transition to enable them to install and calibrate the system.

2.2 CIE colour co-ordinates

The CIE colour co-ordinate system[3] specifies light signal colours in a manner that allows quantitative measurements of colour to be made and hence enables the colour characteristics of PAPI units to be specified and verified.

A pilot using the PAPI should see either a red or white signal light emitted from each projector. In practice there is a narrow region at the interface between the two colours where the CIE signal white and signal red co-ordinates are not complied with. In the original PAPI research reports the stated requirement was for the change of signal from red to white to appear to the pilot of an approaching aircraft to occur over an angle not greater than 3 minutes of arc. Because, such a qualitative statement is clearly subject to a variety of interpretations, it was decided to resort to a quantitative test based on the CIE colour co-ordinate system.

2.2.1 Test procedure

A sample unit from each of the four manufacturers mentioned above was tested at the Trinity House Photometric Laboratory using the optical arrangement shown in Fig 2. Vertical traveises were made and colour measurements taken through the transition sector at positions corresponding to the nominal azimuth zero and $7\frac{1}{2}^{\circ}$ displaced from this axis. Only one lamp was energised in each unit for this test. Most of the readings were obtained at 100% intensity but a small number of measurements were made at 1% intensity, a value that corresponds to the lowest setting likely to be used in service. It should be noted that all the test units were set up to be nominally in focus at ranges (1 km to ∞) greatly in excess of the range used for the measurements. Units are deliberately focussed at long range to optimise the sharpness of the transition at operationally significant ranges (300 m - 9 km). The test procedure produced accurate and repeatable colour co-ordinate measurements for all the light units. By suitably adjusting the telescope aperture it was found practicable to make measurements at 1 minute of arc increments in elevation angle, both by day and at night; an important consideration, bearing in mind that the transition only subtends a few minutes of arc. Cross-reference between observers using the Tintometer[4] also showed high levels of correlation in their colour matching performance.

2.2.2 Colour co-ordinate measurements

The results of the Tintometer tests are shown in Figs 3 and 4 and Tables 1 to 5. The data of primary interest is in Fig 3 which presents the colour change at 1 minute of arc increments during a vertical traverse through the zero azimuth axis at 100% intensity. Inspection of this data shows that the four units exhibited significantly different characteristics when measured in this detailed manner.

Unit A, which in use has a very sharp transition exhibited a very distinct but narrow desaturated blue sector between the red and white signals. Pilots entering this narrow band during an approach perceive it as a white signal of lower intensity. For this unit the angular difference between a CIE signal white and signal red, as measured by the Tintometer is 8 minutes of arc.

Unit B, which like all other units tested was a standard production unit of a type that has been used extensively for flight trials and evaluation, had a measured sector between the red and white signals in excess of 25 minutes of arc; indeed careful inspection of the data for this particular sample revealed that even at angles well displaced from the transition the unit did not emit a signal red light in compliance with the CIE specification. This series of measurements showed the value of a quantitative assessment of the transition sector, but also raised the issue of how this type of unit could have been accepted for use if this was the normal extent of the transition. Further measurements were therefore carried out by the manufacturer. The results were as shown in Figs 5 to 7. A number of important conclusions can be drawn from this supplementary data:

(a) The initial set of Tintometer measurements was not representative of the best performance achievable from this type of unit. A 2 mm movement of the lens resulted

in a significant reduction in the extent of the signal red to white difference to a value of 14 minutes of arc. In addition the red signal properly complied with the CIE specification.

(b) The acceptable tolerances on filter position or lens focal length are small (approximately 0.5%) and will be particularly significant in the design of units of small dimension.

(c) It is possible to generate a wide range of colours by appropriately positioning the filter glass. Fig 6 illustrates this phenomena very clearly. In this figure it can be seen that chromatic aberration produces these coloured signals since they also occur when a blanking plate is inserted in lieu of the red filter glass. It is important that false signals that might be interpreted as guidance signals should not be generated by this process.

(d) Due to aberration, and internal reflections, approximately 5% intensity of white light is present in the red sector of the signal (Fig 7). This tends to desaturate the red signal. However, if it is held to this level the colour will still adequately meet the CIE specification.

(e) In a correctly designed unit the signal colour at angles displaced $\pm\frac{1}{2}^{\circ}$ from the nominal transition will meet the CIE specification and measurements made at greater angles will not result in significantly different chromaticity readings being obtained. If the unit is operated at the rated current the colour co-ordinates at these angles will correspond to those of the filament lamp (white) or filter glass (red) illuminated by the filament lamp.

Units C and D exhibited no pronounced colours at the transition other than a mixture of red and white but as can be seen from Fig 3 both these sharp transition units have an angular difference between the signal red and signal white somewhat in excess of the subjective value of 3 minutes of arc.

The off-axis and low intensity data shown in Fig 4 indicate a broadening of the transition sector, due to aberration, but this is found to be acceptable in use.

2.2.3 Interpretation of colour co-ordinate data

The data given in Figs 3 to 6 shows that it is possible to make accurate laboratory measurements of the signal colours of a PAPI projector using the method described above. However, it must be noted that the measured laboratory values for a unit focussed near infinity but taken over a short range are much greater than the observed extent of the colour transition sector as seen by pilots. The ratio is generally large, being at least 4:1 even in the best units. The difference can be partly explained by the fact that the laboratory measurements are made over ranges much smaller than the operational ranges for which the units are focussed and by reference to the work of Hill[5] and others that formed the basis for the CIE specification. The CIE standard envisages a light signalling system consisting of several colours. The permitted colour boundaries are very restrictive to ensure very high levels of correct colour recognition from the several choices available. In the PAPI system only two signal colours are used. Pilots

are therefore able to be more tolerant in their attribution of signal colour since, unless false signals are generated, the signal will be either red or white. Furthermore, as there are four light units in the system the pilot always has other red or white signals adjacent for comparison. By reference to the work of Hill (reproduced at Fig 8), it can be seen that the PAPI units as measured in the laboratory all exhibit a translation from signal white to a point on the CIE diagram inside a high probability of recognition boundary for a red signal within a 3 minute of arc sector although the sector from white to true red is much larger. In the PAPI system it seems highly likely that at the larger boundary pilots regard the signal seen as being red. For the PAPI it seems reasonable and justifiable therefore, to regard the extended boundary shown in Fig 9 as the practical boundary for laboratory measurements of the red signal. It may therefore be concluded that units should have no more than a 3 minute of arc sector between this extended boundary and the signal white boundary. This recommendation is supported by the work of Frederiksen in Copenhagen[6].

Although operationally acceptable light units can have an angular difference between white and red in excess of 3 minutes of arc when measured by instrumental methods, there is a practical limit to the extent of this sector. The data obtained in the trials at Dungeness suggests that the angular difference between a measured white signal and a measured red signal, according to the CIE specification, should not exceed 15 minutes of arc.

The sharpness of the transition depends on the degree of convergence of the beam illuminating the filter and projector lens; the more nearly parallel this is, the greater the tolerance in observing distance or lens-filter separation.

2.3 Long range colour-matching tests

2.3.1 Observation method

Observations were carried out on samples of the units tested at Dungeness over a 2 km range at RAE Bedford. Two units, operating at the rated current for the lamps were sited 10 m apart (see Fig 10). One unit was adjusted so that the observer received a red signal at an angle displaced approximately 1° from the transition zone. The other unit was then adjusted in elevation in 1 min incremental steps so that the observer saw a sequence of signal colours from red to white. At each increment a number of observers were required to record whether or not the signal colour seen matched the red reference light or was some other colour. In this way a subjective measure of the extent of the transition was obtained. The process was repeated with the incremental changes being made in the reverse direction (white/red).

2.3.2 Results of colour-matching

The method proved easy to use and produced repeatable results with a unanimous agreement between observers as to the presence or absence of a colour match. The results clearly indicated that in the two-colour PAPI system all the units tested are seen to be unmistakably red or white lights except for a very narrow transition sector which never exceeds 3 minutes of arc and is generally only 2 minutes of arc in extent. Even at the edges of the beam the observed transition is not significantly increased.

This colour-matching method reproduces the operational viewing circumstances. It is easy to conduct tests and this technique readily detects unsatisfactory transition characteristics. It can therefore be used as confirmation that PAPI units meet the sharp-transition specification requirements.

2.4 The datum setting angle can be identified either as the mid-point between the white signal and the extended red signal if the transition is measured by the method described in section 2.2.1, or as the mid-point between the angles at which white and red signals are identified if the method of measurement described in section 2.3.1 is used.

3 INTENSITY

3.1 Isocandela diagram

The isocandela diagram specified for PAPI is shown in Fig 11. The intensity and beam dimensions meet the angular coverage and range requirements specified by ICAO (Ref 7, section 5.3.6.14). It will be noted that ICAO requires the unit to be visible at a range of 7.4 km over a sector of $\pm5^{\circ}$ ($\pm7\frac{1}{2}^{\circ}$ at night) but it must be stressed that this requirement does not completely specify the beam dimensions. Light is required at angles considerably greater than those given above for the following reasons.

Ref 8 (Fig 4-1) indicates a requirement to support operations where the aircraft may be displaced from the centreline at angles up to $\pm15^{\circ}$. A similar lateral beam spread, at a reasonably low intensity is also needed to allow the pilot to receive PAPI guidance right down to the threshold - an important feature of the system.

The elevation beam-spread is determined not only by the requirements of Ref 7, section 5.3.6.4, but by considerations relating to the use of PAPI for glideslope angles well in excess of 3°. It is essential that this beam-spread be provided to ensure that PAPI systems can meet all the envisaged future developments (STOL and helicopter operations). Light units that only meet the requirements of Ref 7, section 5.3.6.4 and do not meet the broader requirements of Fig 11 are not acceptable as PAPI units.

A PAPI unit should be deemed to meet the isocandela requirements provided that the relevant minimum intensity specified within each ellipse shown on Fig 11 is provided over at least 98% of the included area.

3.2 Intensity changes at the transition

During the course of the colour co-ordinate tests at Dungeness, the opportunity was taken to make intensity measurements for the various types of unit through the plane of the transition. The results are shown in Fig 12. They each relate to a single lamp; a three-lamp unit would therefore emit three times the intensity shown. The intensity in the red sector is recorded as being substantially lower than the true value due to a lack of sensitivity to red light in the measurement photocell. Nevertheless the data is worth reviewing because it shows in fine detail how the intensity of the unit changes at the transition. The colour transition occurs at the point of inflection of the intensity plot confirming the practical observation that the very rapid change of

intensity that occurs enables the interface to be readily identified and enhances the visual impact of the sharp colour transition.

3.3 Filter transmission

The red light signal in the PAPI is produced by locating a red filter in the upper half of the projector aperture in the focal plane of the projector lens. The intensity of the red light signal is dependent on the light output of the filament that also provides the white signal and the transmission value of the filter material. This transmission value should never be lower than 15% and generally will be in excess of 18%. For test purposes the filter transmission should be measured for a sample inserted into the PAPI projector and operating at the normal stable working temperature and illuminated by the normal lamp used in that unit. The filament temperature of the lamp should be 2854 K if the measurement is made using a V_λ corrected photocell and the measurement system should be calibrated against a filter of known performance.

4 ENVIRONMENTAL FACTORS

4.1 Causes of contamination

Contamination of the lenses is a well-recognised potential source of problems for any light projection system used on an airfield. Deposits on the lens surfaces can modify the beam dimensions, intensity and colour of the signal emitted. Care must therefore be taken to prevent such problems occurring. The main causes of contamination are rain, either by direct impingement or by splashing, the condensation of moisture, the formation of ice and deposits of snow.

4.2 Design solutions

The lens surfaces can be protected from the problems caused by rain by the careful design of the unit shape. Hoods and splash plates can fulfil this requirement.

In temperature climates the most prevalent potential cause of serious difficulties is condensation, coupled in the winter months with deposits of frost. All PAPI units must be designed to completely prevent this problem causing any difficulties. Tests carried out at RAE during the period September 1981 to April 1982 showed that a small amount of heat energy constantly applied to the unit completely prevented the formation of condensation and ice on occasions when identical unheated units were subject to severe condensation or icing (over an ambient temperature range of $+10^{\circ}C$ to $-18^{\circ}C$), Table 6. The amount of energy needed is that which will keep the lens surfaces above the ambient temperature. In the four types of unit tested this objective was satisfactorily achieved either by the fitting of special heater elements inside the light unit (as little as 20 W per lens) or by running the lamps in the units at a low voltage (equivalent to 10-20 W per lens). At this voltage the filament is a dull orange in colour and emits virtually no light.

If preventative measures are not taken, then it must be assumed that light units may require at least 15 min operation at full intensity before use to ensure the removal of condensation or frost from the surfaces of the lenses.

In the very cold climates experienced in Scandinavia, deposits of snow may also be significant. One UK manufacturer has successfully fulfilled the requirement by installing a 120 W heater inside the light unit. This has been totally successful over four winter seasons.

It should be noted that the PAPI unit is virtually a sealed box having no slit as in the VASI or T-VASI. It is thus largely immune from the ingress of airborne materials such as rain, snow or sand.

5 CONCLUSIONS AND RECOMMENDATIONS

The PAPI system originally described in Ref 1 has subsequently been the subject of considerable engineering development and operational evaluation. Lessons learned from this work as they relate to the optical design of the PAPI light unit have been reported and reviewed in this Memorandum. In particular test methods for measuring the sharpness of the colour transition have been developed and are reported in this Memorandum.

Experience with the PAPI system has shown that it is essential to ensure that the light units are designed to provide the characteristics described in Refs 1 and 2, particularly in relation to the beam-spread and the sharpness of the transition. Environmental conditions that can adversely affect the performance of the PAPI must be fully catered for in the design of the units.

The data and test methods presented in this Memorandum should form the basis of specifications and guidance material. It is recommended that the standards and recommended practices summarised in the Appendix should be applied to all PAPI systems.

Appendix

(1) The PAPI light unit shall not emit any signal colour, as defined in Ref 3, other than red and white.

(2) The red signal emitted $\frac{1}{2}^{\circ}$ below the transition plane and the white signal emitted $\frac{1}{2}^{\circ}$ above the transition plane shall comply with the signal colours of Ref 3. Measurements at angles greater than $\frac{1}{2}^{\circ}$ from the transition shall not produce co-ordinate values significantly different from those measured at the $\frac{1}{2}^{\circ}$ position.

(3) The angular subtense between the angles at which a signal white and a signal red can be measured shall not exceed 15 minutes of arc.

(4) The angular subtense between the angle at which a white signal and a signal measured as lying within the extended red area shown in Fig 9 should not exceed 3 minutes of arc.

(5) Compliance with the requirements ((3) and (4)) shall be verified by using the method described in section 2 or a similar technique. The lampway under test shall be focussed for normal operation and it shall be operated at the rated current for the lamp.

(6) When compared with a reference light (a unit of the same design set at an angle at least $\frac{1}{2}^{\circ}$ into the red sector) the PAPI unit shall appear to an observer at a range of 2 km to exhibit the two distinct signal colours (red and white) separated by an angular difference of not more than 3 minutes of arc. This test should be done with all lampways lit.

(7) The isocandela diagram shown in Fig 11 shall be complied with. A tolerance of 5% less than the area shown for any area bounded by a particular intensity value shall be permitted to allow for small irregularities in the beam distribution.

(8) The red filter material in the projector shall have a transmission of at least 15%. The measurement shall be made with an instrument that has been calibrated against a known standard glass.

(9) The unit shall be designed to minimise the direct impingement or splashback of rain on lens and window surfaces.

(10) The unit shall have a means of preventing condensation or the formation of ice on the lens and window surfaces. This can be achieved for lenses in a number of ways including:

- a special heater (20 W per lens),
- continuous operation of the unit with provision to set the power input to a low value (20 W per lamp) when the unit is not in use.

(11) The datum setting angle shall be the mid-point between those angles where the boundaries of the red and white signals are measured.

Table 1

APPARATUS A, RIGHT-HAND LIGHT

	Elevation	Bearing	Intensity	R	Y	B	X	Y
1	+20 ft	0^{o}	100%	0	0.2	1.2	0.429	0.404
2	+10 ft			0	0.4	1.4	0.428	0.406
3	+8 ft			0	0.5	1.4	0.429	0.407
4	+6 ft			0	0.5	1.4	0.429	0.407
5	+4 ft			0	0.6	0.7	0.442	0.413
6	+2 ft			0	0.7	0.4	0.448	0.415
7	+1 ft			0	0.7	1.4	0.431	0.410
8	0 ft			0	0	5.4	0.348	0.357
9	-1 ft			0	0.3	10.0	0.274	0.293
10	-2 ft			4.0	0	12.0	0.266	0.225
11	-3 ft			11.0	0	12.0	0.316	0.210
12	-4 ft			20.0	0	11.0	0.420	0.233
13	-5 ft			31.0	0	10.0	0.543	0.268
14	-6 ft			35.0	0	9.0	0.588	0.284
15	-7 ft			46.0	0	9.0	0.644	0.293
16	-8 ft			49.0	0	9.5	0.652	0.292
17	-9 ft			63.0	0	8.5	0.688	0.296
18	-10 ft			68.0	0	8.0	0.694	0.296
19	+10 ft	0^{o}	1%	4.0	13.0	0	0.542	0.425
20	-10 ft			70.0	0	9.0	0.696	0.293
21	+10 ft	$7\frac{1}{2}^{o}$	100%	0	0.5	1.4	0.429	0.407
22	+5 ft			0	0.4	1.1	0.433	0.408
23	-5 ft			9.0	0	2.5	0.501	0.338
24	-10 ft			32.0	0	6.5	0.602	0.300
25	-15 ft			47.0	0	7.0	0.658	0.302
26	-20 ft			59.0	0	6.0	0.684	0.302

Table 2

APPARATUS B, RIGHT-HAND LIGHT

	Elevation	Bearing	Intensity	R	Y	B	X	Y
1	+30 ft	0°	100%	0.4	0	0.7	0.440	0.400
2	+20 ft			1.3	0	0.7	0.452	0.392
3	+15 ft			3.2	0	0.9	0.470	0.377
4	+13 ft			4.2	0	0.7	0.485	0.371
5	+11 ft			6.4	0	1.3	0.497	0.356
6	+9 ft			10.5	0	2.4	0.516	0.335
7	+7 ft			17.0	0	3.6	0.548	0.318
8	+5 ft			27.0	0	6.2	0.576	0.299
9	+3 ft			35.0	0	7.0	0.612	0.298
10	+1 ft			38.8	0	6.8	0.631	0.301
11	-1 ft			40.0	0	5.0	0.648	0.309
12	-3 ft			40.5	0	4.0	0.654	0.312
13	-5 ft			41.0	0	3.2	0.659	0.313
14	-10 ft			43.0	0	3.1	0.663	0.313
15	-20 ft			46.0	0	3.3	0.669	0.311
16	-30 ft			47.0	0	4.0	0.669	0.310
17	-60 ft			50.0	0	4.0	0.674	0.309
18	+20 ft	0°	1%	5.5	12.0	0	0.556	0.412
19	+10 ft			23.0	0	0	0.623	0.330
20	-10 ft			60.0	0	0	0.688	0.309
21	-20 ft			60.0	0	0	0.688	0 309
22	+10 ft	$7\frac{1}{2}^{\circ}$	100%	2.5	0.3	0	0.481	0.390
23	-10 ft			44.0	0	4.0	0.662	0.311
24	-60 ft			49.0	0	4.0	0.672	0.309
25	-70 ft			60.0	0	4.0	0.687	0.305

Table 3

APPARATUS B, LEFT-HAND LIGHT

	Elevation	Bearing	Intensity	R	Y	B	X	Y
1	+12 ft	0^{o}	100%	0.3	0.7	0	0.458	0.414
2	+10 ft			0.4	0.7	0	0.460	0.413
3	+8 ft			0.4	0.7	0	0.460	0.413
4	+6 ft			0.4	0.6	0	0.459	0.411
5	+4 ft			1.0	0.7	0	0.467	0.407
6	+2 ft			1.6	0.7	0	0.475	0.402
7	0 ft			3.0	0.6	0	0.490	0.390
8	-2 ft			6.0	0	0.2	0.512	0.364
9	-4 ft			10.0	0	2.0	0.519	0.339
10	-6 ft			24.0	0	5.5	0.566	0.303
11	-8 ft			39.0	0	9.0	0.611	0.288
12	-10 ft			42.0	0	8.5	0.631	0.293
13	-12 ft			52.0	0	8.5	0.666	0.297
14	-14 ft			54.0	0	8.5	0.671	0.297
15	-20 ft			55.0	0	8.5	0.673	0.297
16	-60 ft			55.0	0	8.5	0.673	0.297

Table 4

APPARATUS C, RIGHT-HAND LIGHT

	Elevation	Bearing	Intensity	R	Y	B	X	Y
1	+10 ft	0°	100%	0	1.4	0.4	0.454	0.423
2	+8 ft			0	1.1	0.1	0.456	0.421
3	+6 ft			0.1	1.2	0	0.460	0.421
4	+4 ft			0	1.7	0.4	0.456	0.426
5	+2 ft			0.7	0.3	0	0.460	0.405
6	+1 ft			4.0	0	0.4	0.488	0.374
7	0 ft			12.5	0	0.5	0.562	0.341
8	-2 ft			50.0	0	10.0	0.653	0.290
9	-3 ft			66.0	0	8.0	0.692	0.296
10	-4 ft			69.0	0	6.5	0.695	0.298
11	-10 ft			79.0	0	6.0	0.701	0.296
12	+2 ft	0°	1%	5.0	6.0	0	0.540	0.405
13	-2 ft			40.0	0	0	0.666	0.319
14	+5 ft	$7\frac{1}{2}^{\circ}$	100%	1.3	2.5	0	0.484	0.420
15	+2 ft			9.5	0.8	0	0.554	0.358
16	-2 ft			40.0	0	0	0.666	0.319
17	-5 ft			60.0	0	2.0	0.687	0.307

Table 5

APPARATUS D, RIGHT-HAND LIGHT

	Elevation	Bearing	Intensity	R	Y	B	X	Y
1	+10 ft	0^{o}	100%	0	0.6	0.4	0.447	0.414
2	+8 ft			0	1.5	1.1	0.443	0.422
3	+6 ft			0	1.1	1.1	0.440	0.417
4	+4 ft			0	0.4	0.5	0.443	0.411
5	+2 ft			0.7	0.1	0	0.458	0.402
6	0 ft			4.4	1.4	0	0.512	0.387
7	-2 ft			13.5	0.4	0	0.579	0.344
8	-4 ft			27.0	0	3.6	0.608	0.315
9	-6 ft			40.0	0	5.0	0.648	0.309
10	-8 ft			52.0	0	7.0	0.670	0.301
11	-10 ft			55.0	0	8.0	0.674	0.298
12	-12 ft			68.0	0	6.3	0.694	0.299
13	+10 ft	0^{o}	1%	5.0	45.0	0	0.558	0.433
14	0 ft			11.0	40.0	0	0.600	0.394
15	-10 ft			75.0	0	2.0	0.697	0.301
16	+10 ft	$7\frac{1}{2}^{o}$	100%	0	0.4	0.7	0.440	0.410
17	0 ft			0	0.5	0.3	0.448	0.413
18	-10 ft			42.0	0	1.5	0.666	0.316
19	-20 ft			47.0	0	4.0	0.669	0.310

Table 6

CONDENSATION TEST RESULTS

Air temperature (°C)	Lens temperature (°C)			Power input (watts/lens)		Remarks
	Unheated unit	Special heater	Lamps energised	Special heater	Lamps energised	
13	N/R	22.5	20.5	40	43	
14	N/R	17	20	40	43	
12	N/R	21	19	40	43	
15	N/R	19	21	40	43	
9	N/R	18	18	40	43	
10.5	N/R*	22	17	40	35	
14	N/R	21	18.5	40	35	
14	N/R	23	19	40	35	
[illegible] 5	-0.5*	15	3	40	18	Frost on lens
[illegible].0	N/R	12	7	40	18	
N/R	N/R*	N/R	N/R	40	16	
N/R	N/R*	N/R	N/R*	40	4	Filament just lit
N/R	N/R*	N/R	N/R	40	12	
N/R	N/R*	N/R	N/R	40	9	
N/R	N/R*	N/R	N/R	40	9	Frost on lens
5.5	5*	9	N/R	32	N/R	
-5	N/R*	N/R	N/R	N/R	9	Frost on lens minimum temperature -10°C
5.5	5*	9	N/R	32	N/R	Ground frost
11	11	13	N/R	32	N/R	
5.5	5.5*	8.5	N/R	20	N/R	Overnight frost

* condensation or frost deposit on lens
(readings taken at 0830 hours)

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No.	Author	Title, etc
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3	-	Colours of light signals. International Commission on Illumination - Publication No.39 (1978)
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6	E. Frederiksen	Measurement of colour transition zone of PAPI luminaire. Lysteknik, Copenhagen (1981)
7	-	Aerodromes - Annex 14, Seventh edition, ICAO (1976)
8	-	Aerodrome Design Manual, Part 4, Visual Aids. ICAO Document 9157, AN/901 (1976)

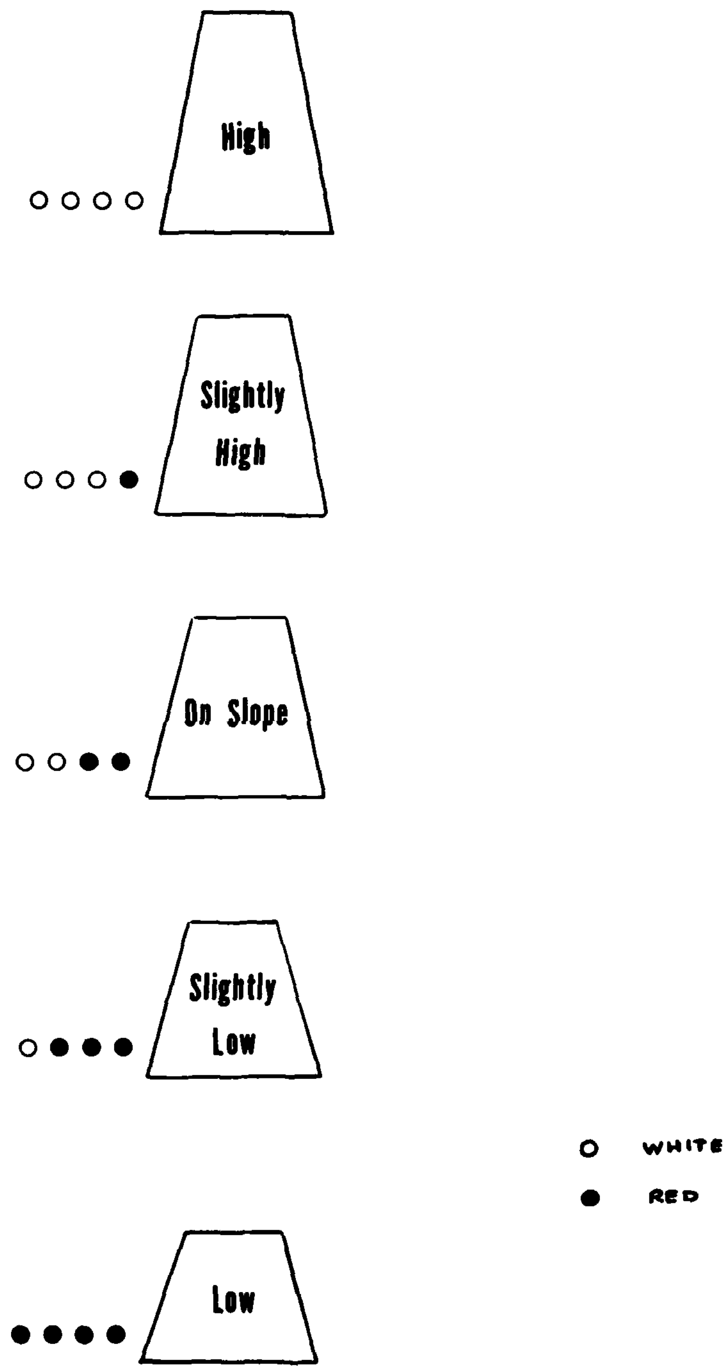
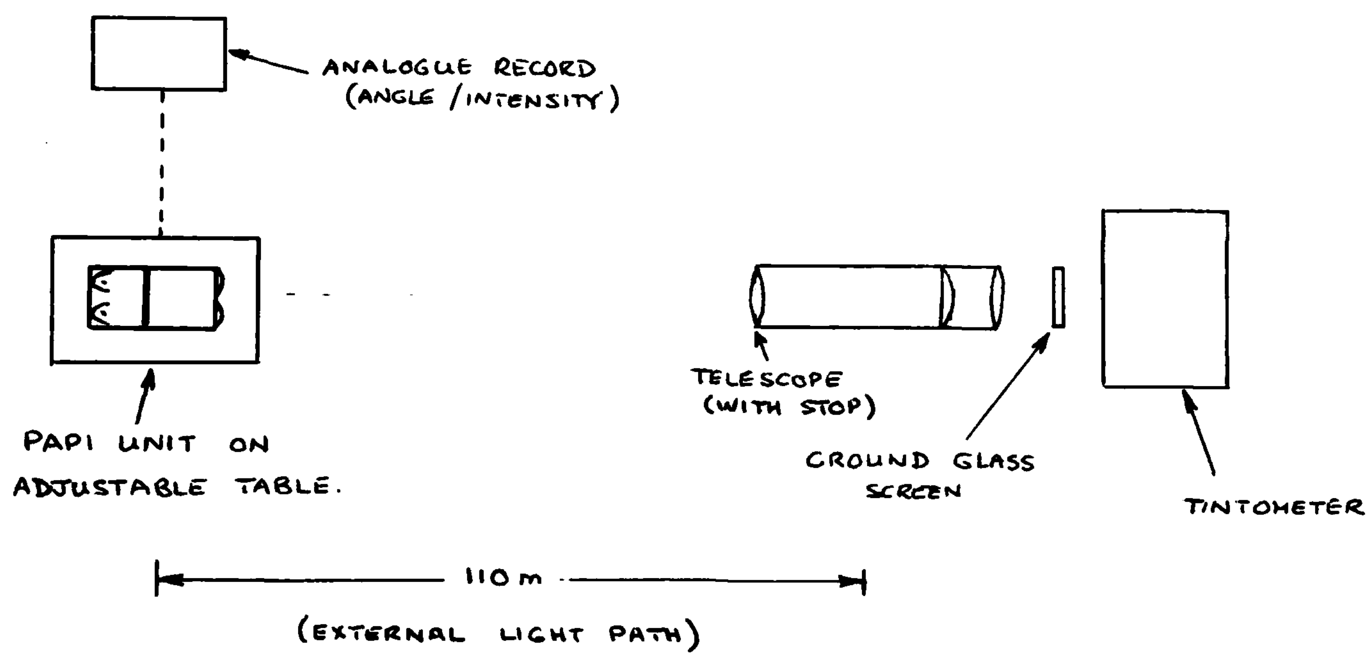


Fig 1 The precision approach path indicator



NOTE. INTENSITY MEASUREMENTS WERE MADE BY REPLACING THE GROUND GLASS SCREEN AND TINTOMETER WITH A SMALL INTEGRATING SPHERE AND PHOTOCELL.

Fig 2 Layout of test laboratory

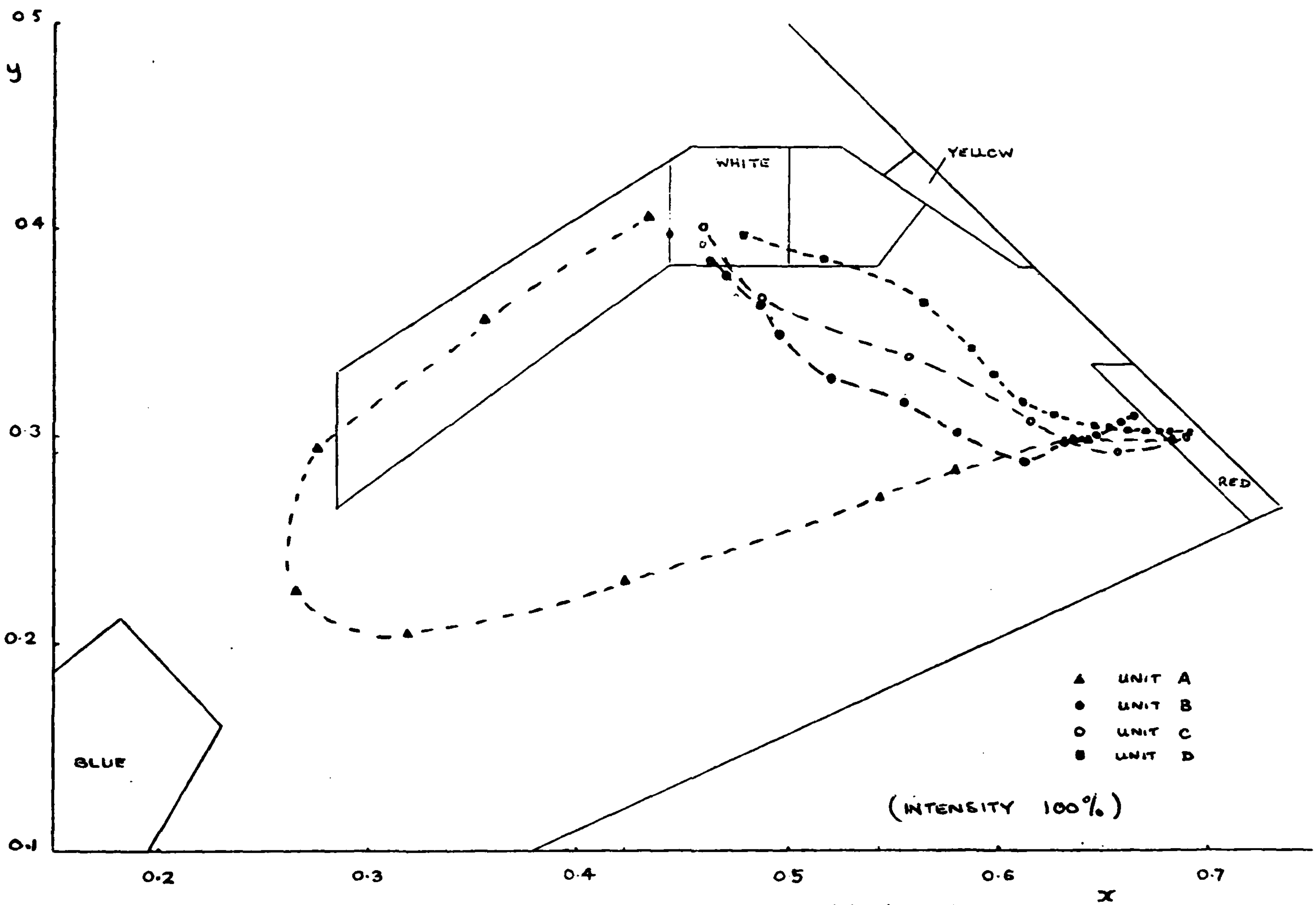


Fig 3 On axis colour co-ordinates measured with tintometer

Fig 4

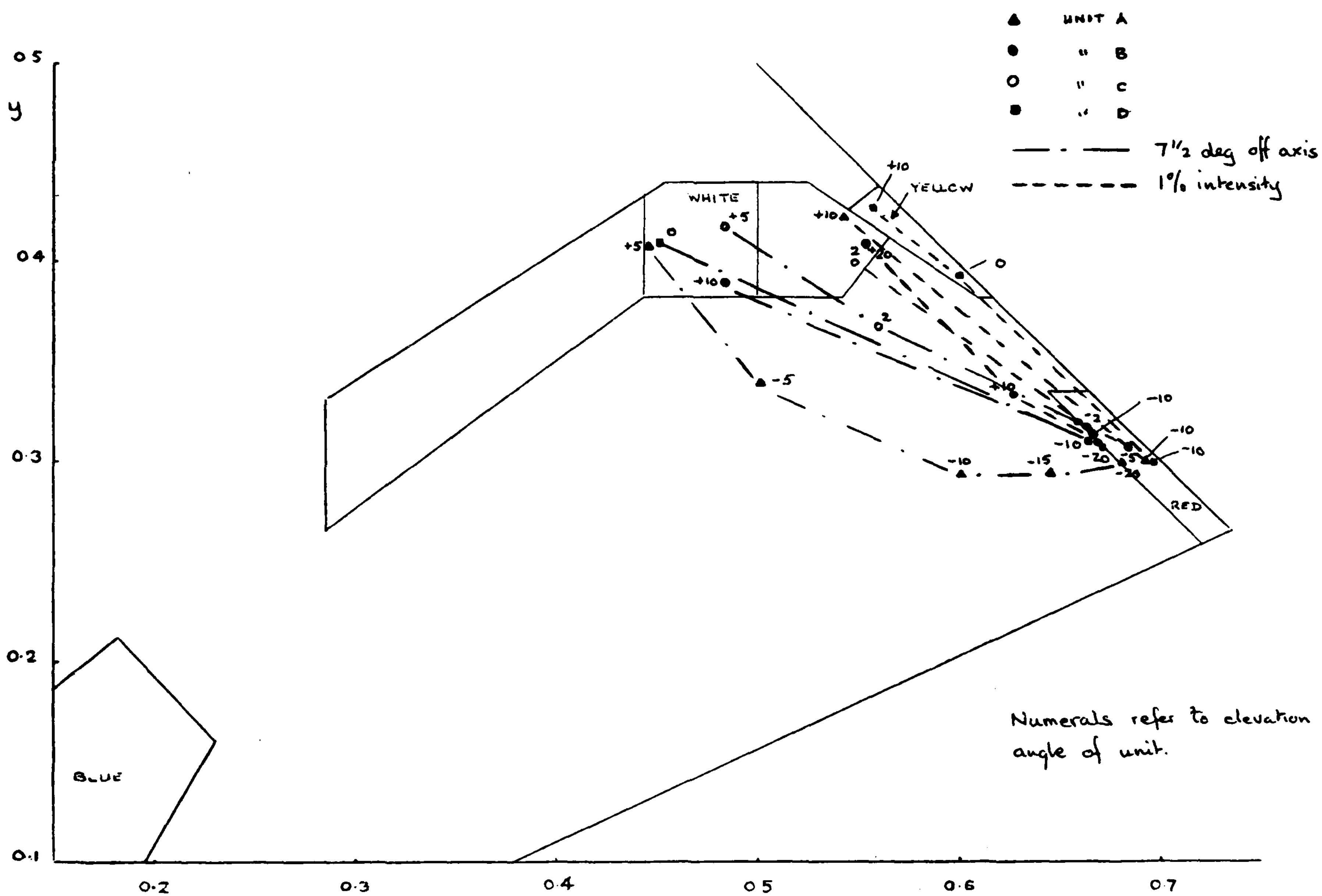


Fig 4 Colour co-ordinates for off-axis and 1% intensity

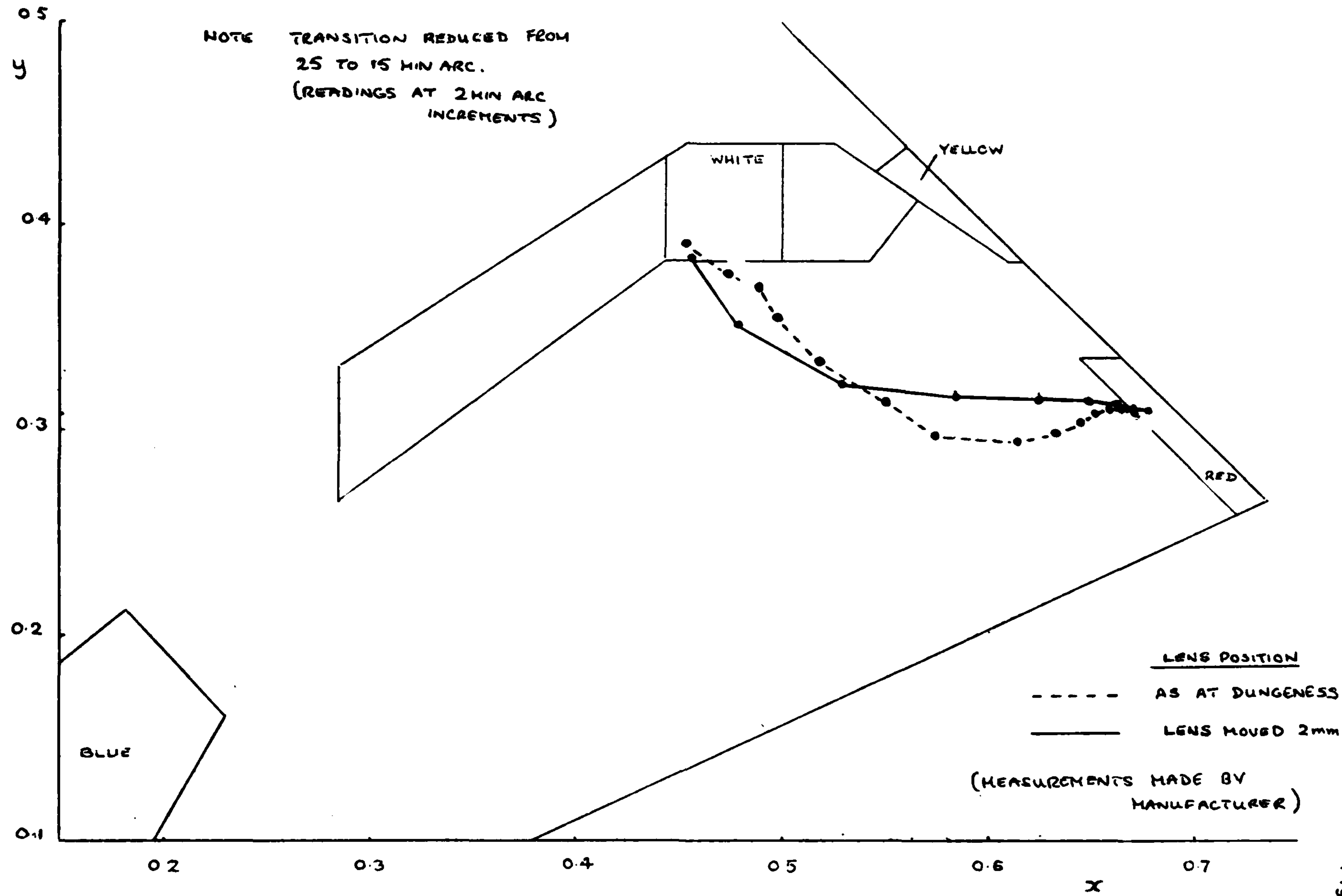


Fig 5 The effect of lens position on transition for unit B

Fig 5

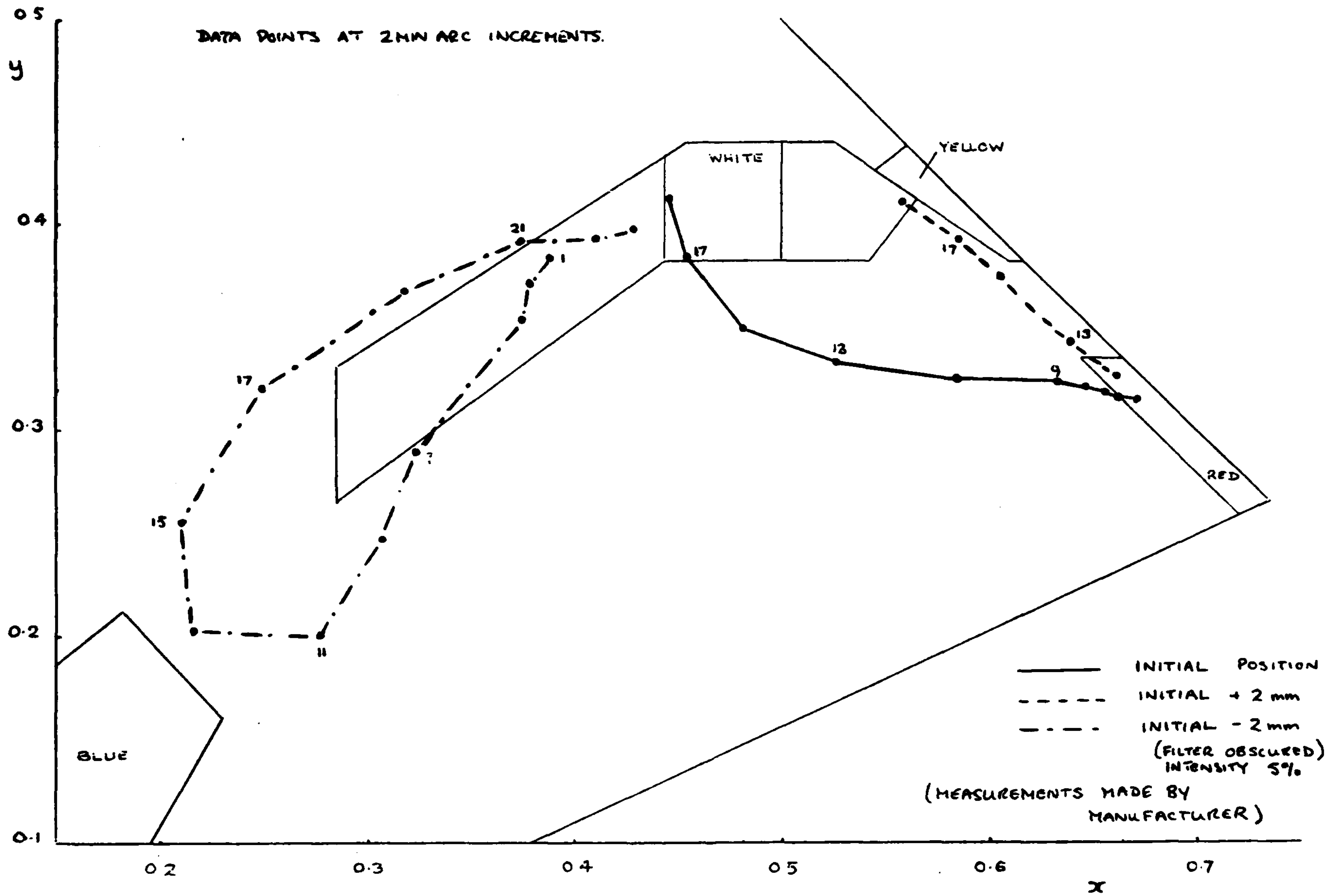
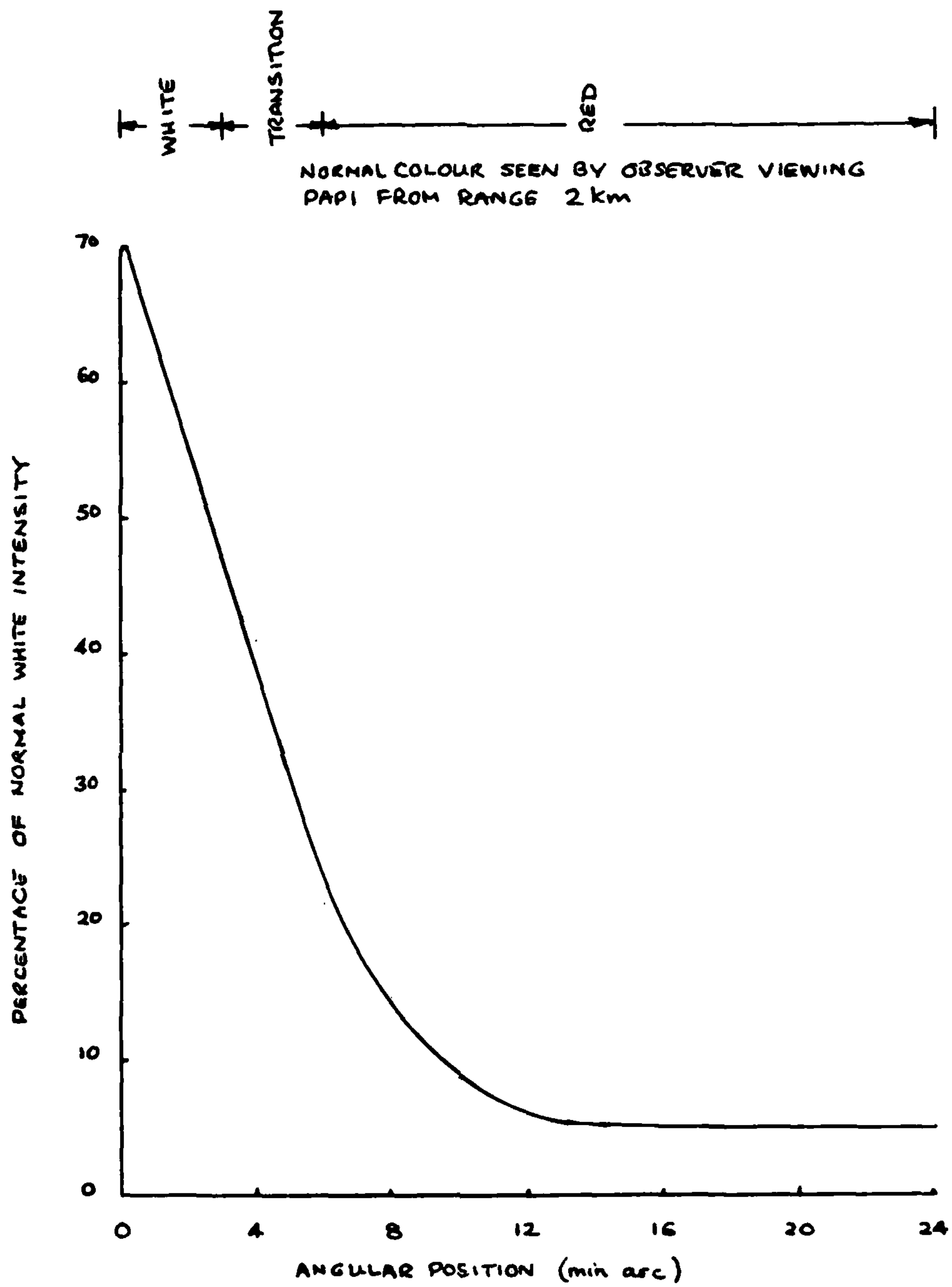


Fig 6 The effect of lens position and obscured filter for unit B



NOTE DATA RECORDED WITH RED FILTER OBSCURED

Fig 7 Light scattered into red sector for unit B

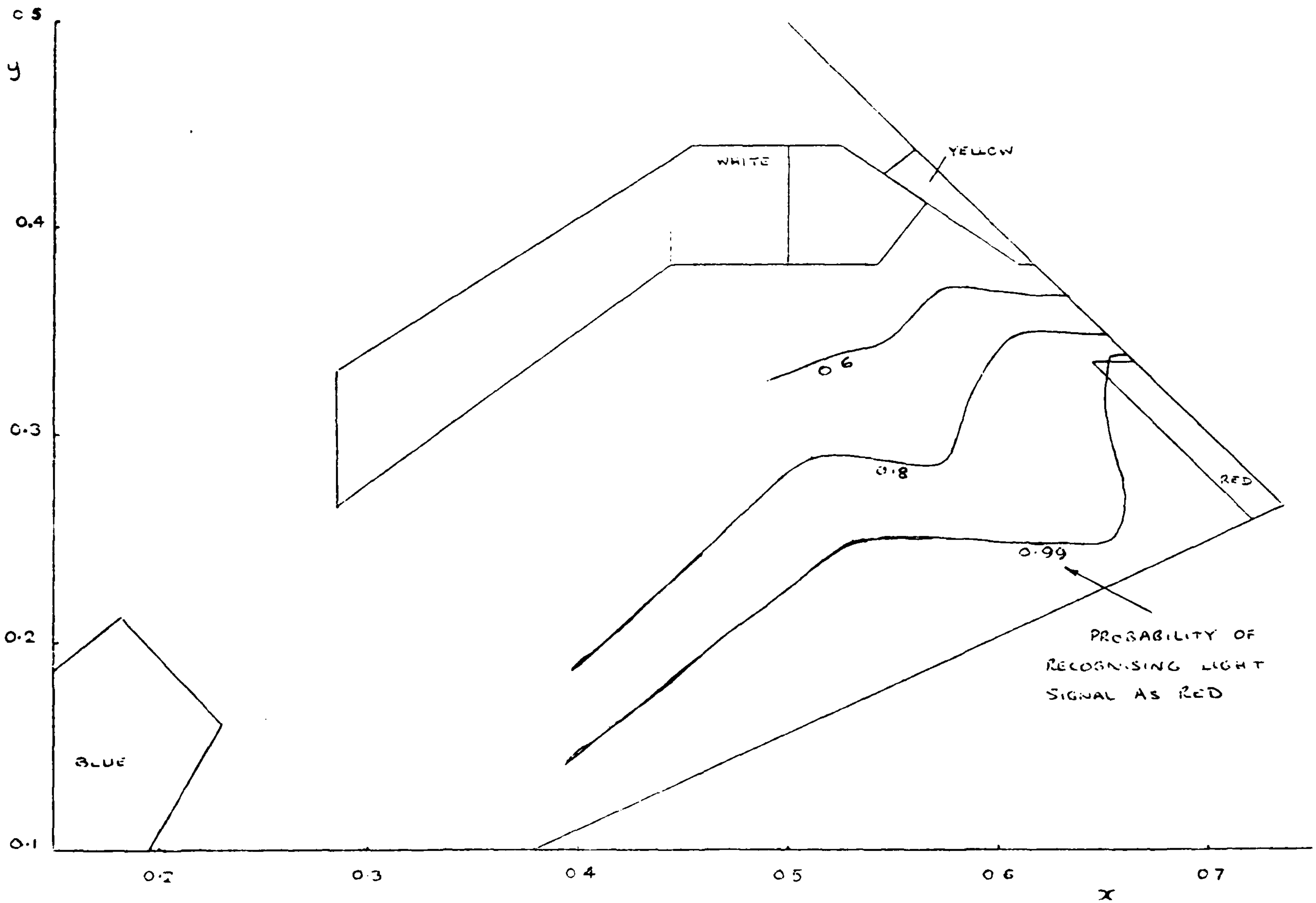


Fig 8 Colour recognition contours for red light signals

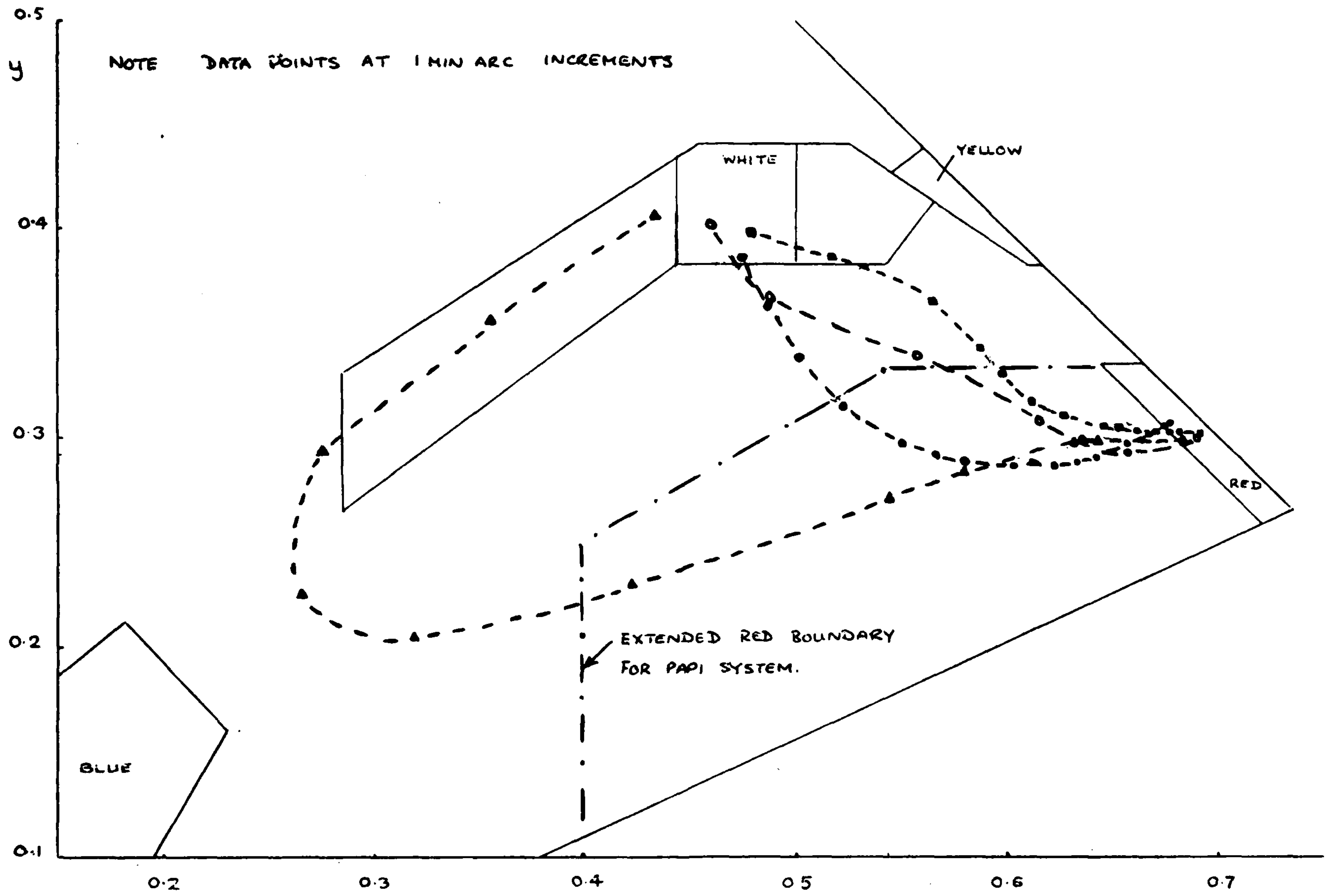


Fig 9 Suggested practical boundary for red PAPI signal

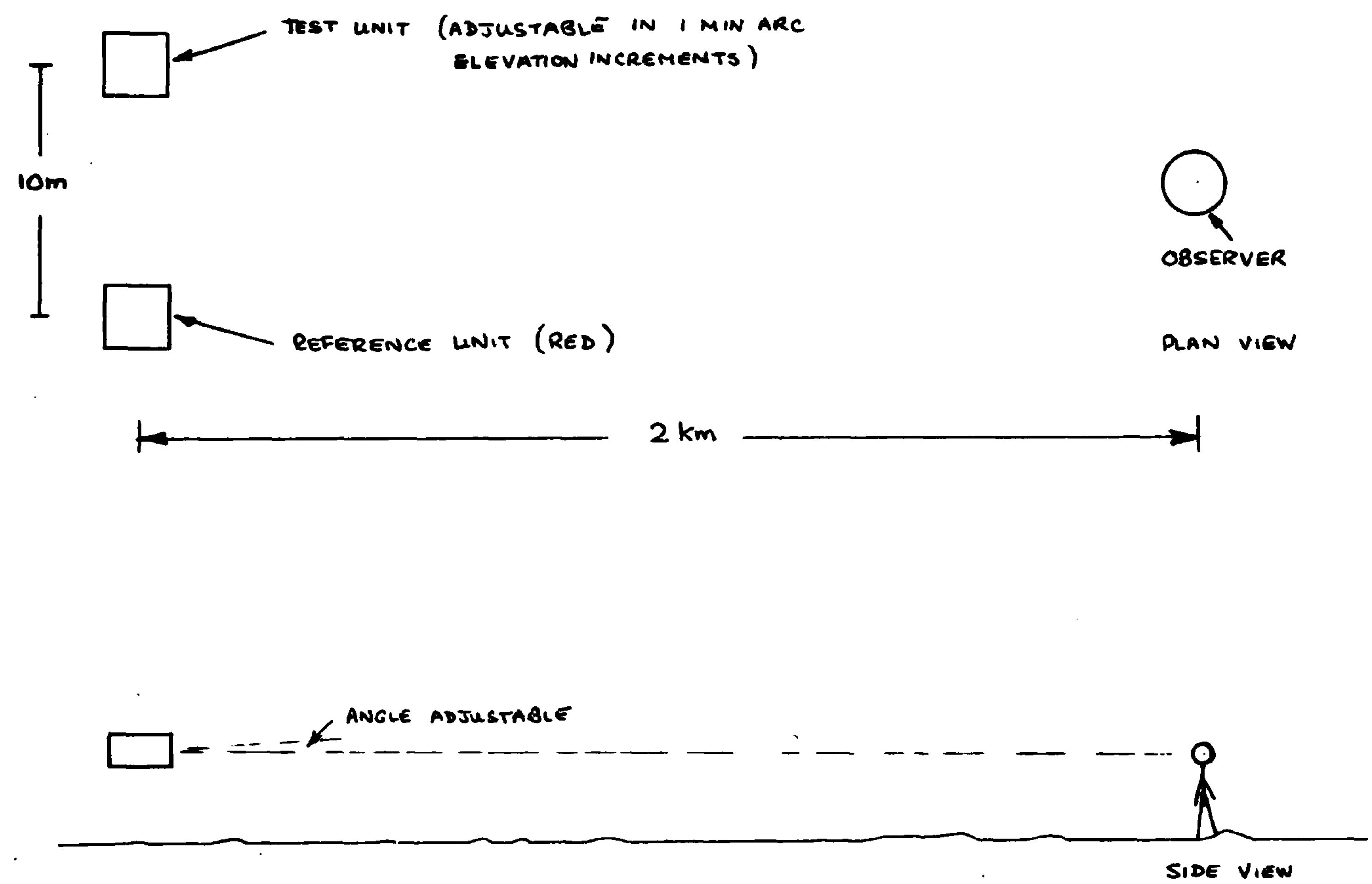
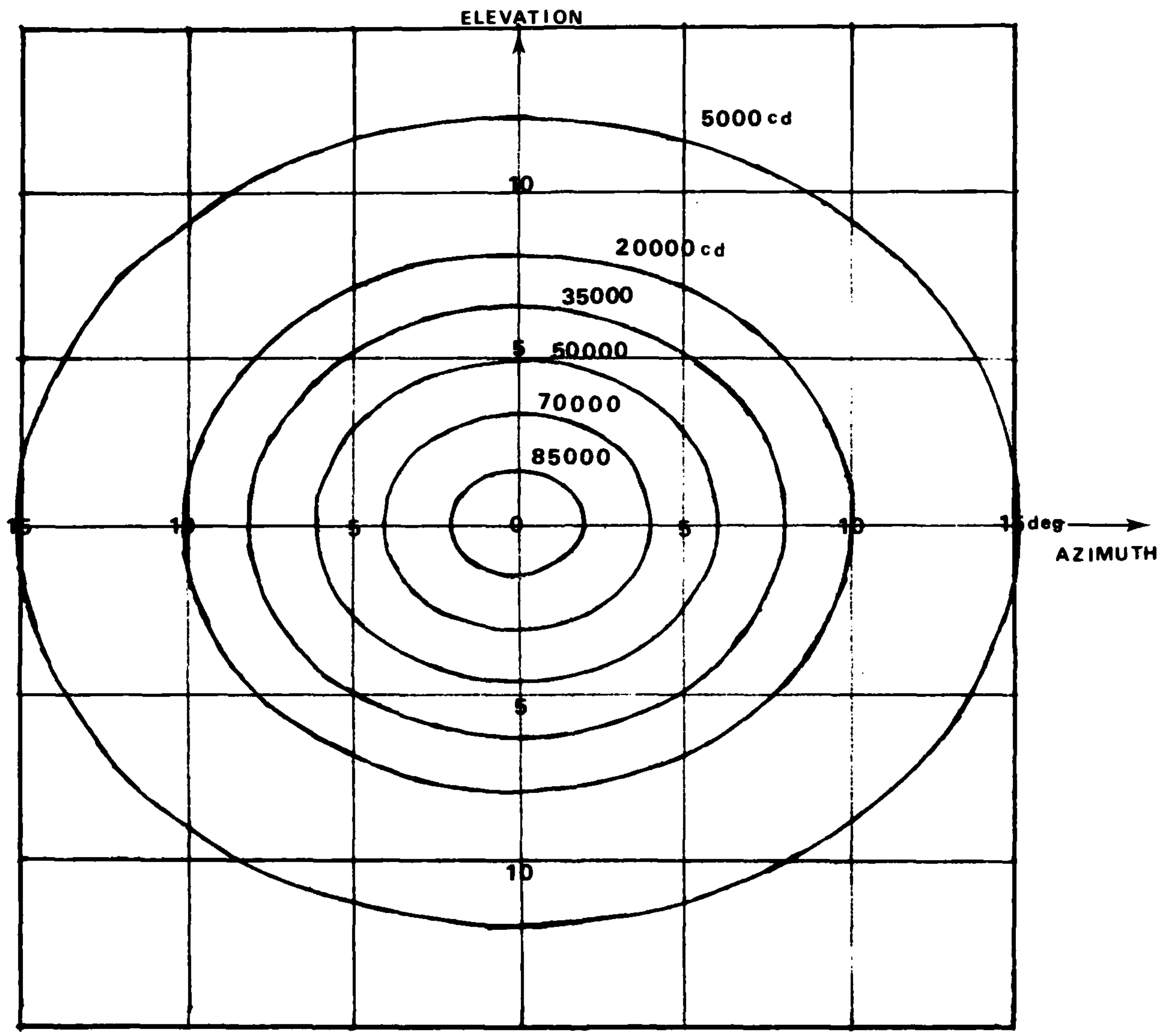


Fig 10 Long range colour matching test layout



NOTES (1) no filter
(2) transmission factor for red (lower) sector not less than 15%

Fig 11 PAPI - isocandela diagram

Fig 12

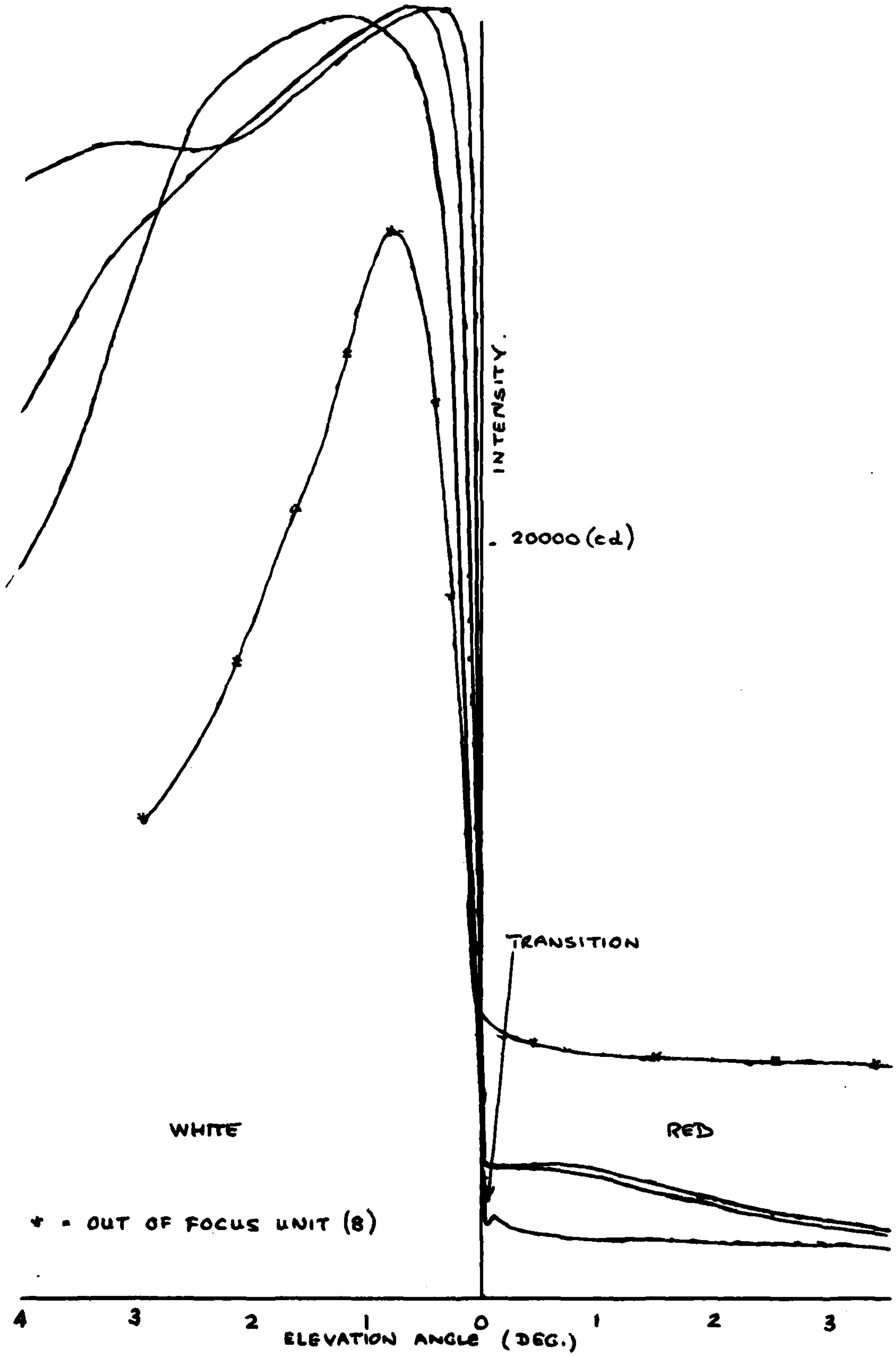


Fig 12 Intensity data showing transition

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNCLASSIFIED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

1. DRIC Reference (to be added by DRIC)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification/Marking
	RAE TM FS(B) 483	N/A	UNLIMITED

5. DRIC Code for Originator	6. Originator (Corporate Author) Name and Location
7673000W	Royal Aircraft Establishment, Bedford, Beds, UK
5a. Sponsoring Agency's Code	**6a. Sponsoring Agency (Contract Authority) Name and Location**
N/A	N/A

7. Title
Development of the precision approach path indicator light unit

7a. (For Translations) Title in Foreign Language

7b. (For Conference Papers) Title, Place and Date of Conference

8. Author 1. Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	Pages	Refs.
Smith, A.J.			July 1982	29	8
11. Contract Number	**12. Period**	**13. Project**	**14. Other Reference Nos.**		
N/A	N/A				

15. Distribution statement
(a) Controlled by – Unlimited
(b) Special limitations (if any) –

16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Approach path indicator. Colour measurement.

17. Abstract

F5910/1

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